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Composite Propeller Performance Monitoring with Embedded FBGs

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Introduction: Composite propeller blades are of Navy and commercial interest because they offer significant advantages in reduced weight, reduced maintenance, and increased performance. Potential benefits include design flexibility not achievable with metal that can increase mechanical efficiency, cavitation reduction, propeller weight reduction, and underwater blade replacement, to name a few.

One of the major benefits claimed for fiber Bragg grating (FBG) sensors is their ability to be embedded in composite materials with minimal effects on the performance of the material. In spite of embedded FBGs being routinely touted during discussions of smart materials, most reports dealing with embedded FBGs have been limited to simple structures such as composite plates or beams and tested under laboratory conditions. NRL was asked to contribute embedded FBG sensors as part of a composite propeller manufacturing and testing program being put together in the Propulsion and Fluid Systems Division of the Naval Systems Warfare Centers Carderock Division. This was an opportunity to both advance the state of the art in FBG sensing and provide propeller designers with the high-quality strain data that can lead to improved fluid dynamics models and better propeller designs.

Optical Design: Embedding FBG sensors in composite materials poses two major challenges. Bend-induced losses must be minimized, and the fiber optic leads must exit the material with sufficient fiber to allow external connections. These challenges mean that manufacturers must learn how to handle optical fiber and may need to modify their manufacturing processes to accommodate the sensors and preserve the fiber leads. Problems in these areas were encountered and overcome during this effort.

The sensor wavelengths and locations were chosen based on strains predicted by a finite-element model (FEM) of the propeller. Figure 10 shows sensor locations for both the pressure and suction side arrays. For reference purposes, we number the sensors starting from nearest the hub. The sensor spacings (in mm) are measured along the mid-chord of the blade, relative to the base of the propeller blade. The sensor wavelengths were chosen to ensure that wavelengths would not cross under worst-case loading conditions. All sensors were manufactured in polyimide-jacketed fiber, and the FBGs were rejacketed to maximize physical strength and strain transfer. Optical signals are transferred

between the stationary demodulation system and the rotating propeller. This is done by using a commercial fiber optic rotary joint designed for bidirectional signal transfer and capable of rotation rates up to 2000 rpm and underwater operation. Figure 11 shows the downstream end of the propeller mounted in the water tunnel, with the stationary fiber extending out of the rotary joint.

Results: Measurements were made using the suction side array under thrust loads that varied from 80% to 120% of design thrust with the propeller downstream of a four-quadrant wake screen. The wake screen is divided into eight equal angle segments that alternate between low- and high-velocity flow regions. Thirty seconds of strain data were recorded at each thrust setting. Figure 12 shows a short segment from one measurement at 100% of design thrust. This figure shows the strains from all five suction side sensors and the unsteady dynamics produced by the wake screen. Sensors 1 and 2, those nearest the blade root, look moderately sinusoidal; sensors 3 and 4, which are roughly mid-blade, show additional frequency content; sensor 5 shows only modest fluctuations. It's also interesting to note that sensor 3 shows the largest peak-to-peak fluctuations. Detailed interpretation of these results and how they relate to the flow fields awaits the results of a coupled unsteady flow/propeller mechanics model being developed by Y.L. Young at Princeton University.

Conclusions: We have successfully embedded fiber Bragg grating strain gauges in composite propeller blades and measured dynamic strains while the propeller was being tested in a water tunnel. Preliminary data analysis shows that the mean strains scale with load, while the strain fluctuations due to the presence of a wake screen increase as load decreases. Quantitative analysis awaits comparisons between the measured strains and the results of unsteady flow hydrodynamics modeling.

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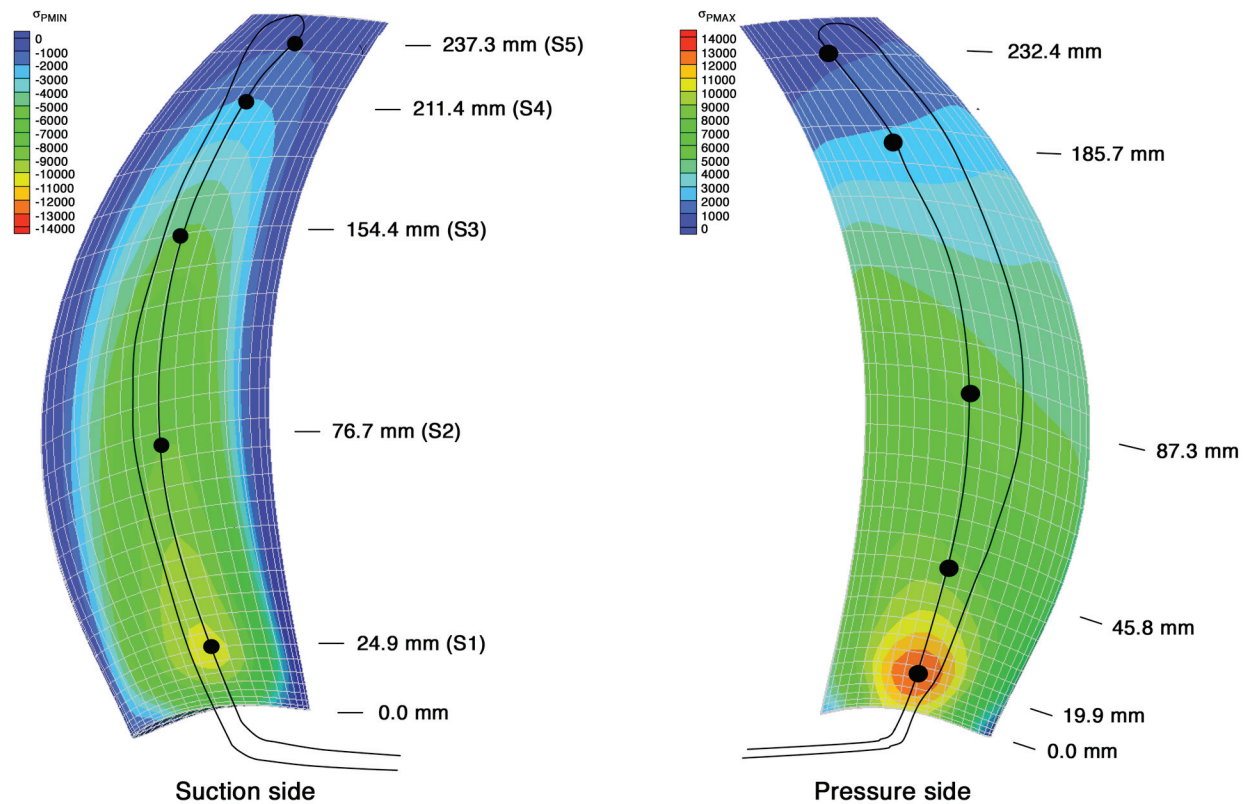


FIGURE 10
Predicted strain values for design thrust and sensor locations (in mm) for both sides of the propeller. The designations S1 – S5 identify the suction side sensors.

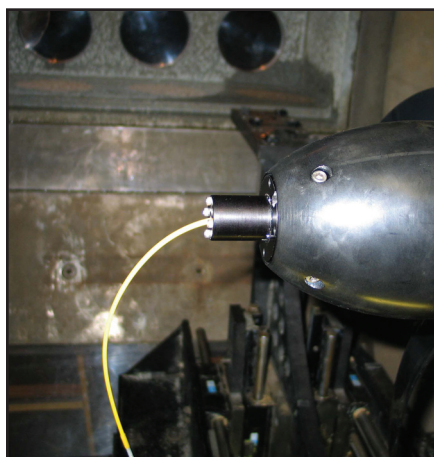


FIGURE 11
The downstream end of the propeller, showing the stationary side of the fiber optic rotary joint and the optical fiber carrying signals to the data acquisition system.

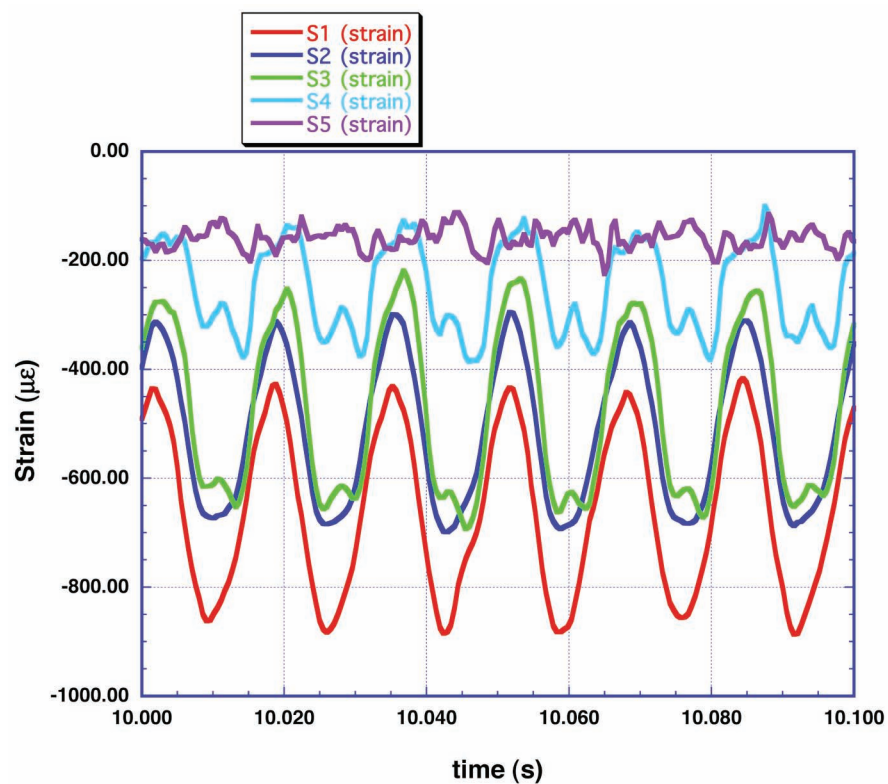


FIGURE 12
A short segment of data, showing the dynamic strains on all five suction side sensors for the propeller operating at design thrust behind the wake screen.